Regional and Historical Fire Weather Patterns Pertinent to the January 1994 Sydney Bushfires

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The bushfires in Sydney during January 1994 drew an unprecedented response from the public, the media and fire-fighters across the nation. While ignition sources, fuels, terrain and suppression forces affected the number, severity, spread and impact of the fires, weather also had a major effect. We examined the historical weather record maintained by the Bureau of Meteorology for 7 weather stations in the region of Sydney (Wollongong, Sydney, Liverpool, Parramatta, Bankstown, Richmond and Katoomba). Weather data were considered in the form of the McArthur forest fire danger index (FFDI). The FFDI has a maximum of 100 and registers 'extreme' if over 50. During the 1994 fire period, the maximum 3 pm value among all stations was 93 at Richmond. Record January values of FFDI were noted for 5 of the 7 stations (the exceptions being Katoomba and Wollongong). Data for January 1994 from Richmond and Bankstown stood out in that: one 3pm FFDI value at Bankstown was a record for any month while one for Richmond was an equal record; both stations had unprecedented numbers of 'extreme' days (Richmond had 5 in 6 days while Bankstown had 4).

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INTRODUCTION

The fires in the Sydney region in January 1994 resulted in loss of about 230 houses or similar major buildings (C. Ramsay, personal communication) and human life. Most of the damage was around a relatively small fire (Como–Jannali). Fires included those burning in and around Royal National Park, Ku-Ring-Gai National Park, Lane Cove National Park, The Glen Reserve (Como–Jannali) and the Blue Mountains. Fire fighters came from all over Australia to assist. On January 8, approximately 10,000 fire fighters with around 1,000 fire-fighting 'units' were engaged in the greater Sydney Region (including the Blue Mountains — Department of Bush Fire Services 1994). The fires elicited a Coronial Enquiry, a NSW Cabinet Enquiry and a NSW Legislative Assembly Select Committee of Enquiry. The main fire period in the greater Sydney area was between January 3 and January 9, 1994.

For major building damage to result from bushfires it is necessary to have ignitions, fuels, buildings in close vicinity to the bush, and inadequate suppression. The last of these is exacerbated by high fire intensities, strong winds, spot-fire generation, steep inaccessible topography, multiple fire events and, controversially, removal of able-bodied residents from their houses.

Inevitably, the question of the possibility of a recurrence of the January 1994 fires arises. Leaving aside social and fuel aspects of the problem, attention focuses on the weather. Was the weather unprecedented? Can the same conditions recur? The latter question could be answered after consideration of the first. Thus, we examined the fire weather of January 1994 in relation to the history of fire weather in the greater Sydney area.

METHODS

We chose 7 meteorological stations in a transect from Wollongong on the coast to Katoomba in the Mountains (Table 1). Fire weather for all stations was examined using the McArthur forest fire danger index (FFDI). This index was developed by McArthur (1967) to provide the basis for the prediction of the rates of spread of fires burning with the wind in eucalypt litter fuels, as well as to indicate fire danger. In this paper FFDI is used only as an index of the severity of fire weather. FFDI was calculated using the equations of Noble et al. (1980). The FFDI has a maximum value of 100 and registers 'extreme' if over 50, 'very high' if between 24 and 49. If calculated values exceeded 100, they were set at 100. (This happened on only two occasions: once for Wollongong and once for Liverpool, neither in 1994). All weather data were purchased from the Bureau of Meteorology.

TABLE 1

Selected weather data for the meteorological stations used in the study together with some geographical data (from Bureau of Meteorology 1988 and maps).

Station	Ave. 3pm screen temperature for January (°C)	Ave. 3pm screen relative humidity for January (%)	Mean annual rainfall (mm)	Mean annual raindays (number)	Elevation of station (m)	Distance from the ocean (km)
Wollongong	23.6	67	1420	132	19	1.5
Sydney	24.5	61	1212	139	42	7
Liverpool	26.5	53	851	104	21	32
Bankstown	26.6	52	905	112	9	26
Parramatta	26.2	56	935	112	60	26
Richmond	27.9	47	805	109	19	51
Katoomba	21.2	58	1412	126	1030	92

To calculate FFDI, data on drought status (*via* a 'drought index' and a 'drought factor'), recent precipitation, time since rain, ambient humidity and temperature, and wind speed in the open at a height of 10 meters are needed. Relatively few stations have all these data. 'Sydney' (Observatory Hill) has the data at 3-hr intervals, at least, while some other stations have the data available at only 9am and 3pm. Few stations have all the data needed for routine calculation of FFDI. Data at 3pm were examined for Wollongong University ('Wollongong'), Sydney Regional Office ('Sydney'), Liverpool Council ('Liverpool'), Bankstown Airport ('Bankstown'), Parramatta North ('Parramatta'), Richmond Airport ('Richmond') and Katoomba Composite ('Katoomba'). The 3-hr data from Sydney have been outlined elsewhere (Gill and Moore 1994).

The drought factor was calculated as the deficit of water in the soil for a hypothetical soil profile holding 200 mm of water. We used the 'soil dryness index' of Mount (1972) for this calculation. In the calculations of evaporation — needed for the daily estimation of water loss from the hypothetical soil profile — equations relating maximum daily temperature to evaporation for both Sydney and Canberra were used — rather than Tables of Mount (1972). The Canberra equations were used for Katoomba because the climate there is closer to that of Canberra rather than that of Sydney. Drought index was initialized by assuming a starting point of 200 mm (i.e. completely dry) and running the calculations until the hypothetical profile was near filled to capacity (within a few mm).

Because daily values of drought index were essential to the calculations of FFDI, missing data disrupt the record. Most of the stations examined had missing data to the extent that initializing the drought index was necessary not just at the beginning of the record but also where a new record began following a break (Table 2). Sydney data for windspeed and direction was also composite (Table 3). The few impossible values in the data were screened out and replaced by values averaged from surrounding data.

TABLE 2

Time periods over which Forest Fire Danger Index (FFDI) calculations were made for each meteorological station (SDI-initializing periods excluded). The numbers of 'extreme' FFDI days for the whole length of record are shown also.

Station	Periods used for FFDI calculations (dates)	Length of record (years)	Ave. 'Extreme' days per annum (number)	'Extreme' days in Jan. 1994 (number)	Ave. 'very high' days per annum (number)
Wollongong	1.1.71–30.6.75				
	1.2.76–31.3.76				
	1.8.76–31.1.94	22	13/22 = 0.6	0	3.7
Sydney	1.3.55–28.2.94	39	25/39 = 0.6	1	4.6
Liverpool	1.1.63–31.12.67				
	1.2.70–31. 1.94	29	17/29 = 0.6	2	6.1
Bankstown	1.3.69–31.12.78				
	1.4.88–31. 1.94	16	24/16 = 1.5	4	7.3
Parramatta	1.9.67–28.2.91				
	1.7.91–31.1.94	26	16/26 = 0.6	2	4.7
Richmond	1.7.64–30.4.69				
	1.2.80–31.1.94	19	40/19 = 2.1	5	16.5
Katoomba	1.3.57–31.12.66				
	3.7.74–31. 1.94	30	6/30 = 0.2	1	4.3

TABLE 3

Locations of anemometers for 'Sydney' data during the FFDI-calculation period.

Dates	Anemometer location
1.3.55–30.4.92	Observatory Hill
1.5.92–28.2.94	Sydney Airport (Kingsford Smith)

Wind data were received in the unit of 'knots' but converted by us to km hr^{-1}. Although noted in 'knots', the original data for Liverpool, Parramatta and Katoomba were taken as Beaufait readings, *i.e.* an ordered multiscale, and expressed as 'knots' on the computer file.

Daily 3pm values of FFDI for each station were averaged for each month of the year, i.e. all January values, all February values etc. Maximum values for each month of each year (e.g. maximum for January 1980, January 1981, January 1982 etc.) were also averaged. These results were plotted together with record maxima for each month.

'Extreme' values of FFDI were identified for each station. Then the relative contributions of wind and dryness to these extreme values were charted (using components of the FFDI equation from Noble et al. 1980). The wind factor was the value 0.0234∗V, an exponent in the FFDI equation. V is the windspeed in the open at 10m height above datum in km hr^{-1}. The 'dryness factor' was [log$_e$ (non-wind portion of FFDI + 1)]. Part of the 'dryness factor' defined here is the 'drought factor' , a variable that has positive values up to 10 (McArthur 1967). For all 'extreme' values for all stations the 'drought factor' was greater than 9.

Wind 'roses' showing frequencies of occurrence of wind directions on the days of 'extreme' FFDI were graphed.

Wind speeds at 3pm for all stations between 1.12.91 and 22.1.94 were compared by regression without transformation of the data. Visual inspection suggested that variance was independent of the mean. Similarly, FFDI values were compared.

Data for '3pm' were 'normally' those for 3pm clock time rather than 3pm Eastern Standard Time during periods of 'Daylight Saving' (Bureau of Meteorology 1988).

RESULTS

During the 1994 fire period, the maximum 3 pm value of FFDI for the region was 93 at Richmond. Record January values of FFDI were recorded at 5 of the 7 stations (the exceptions being Katoomba and Wollongong). FFDI at Bankstown in 1994 was the highest on record for that station. Peak 3pm FFDI for Richmond in January 1994 was equal highest on record. Bankstown had the shortest duration weather data (16 years) and Richmond the next shortest (19 years). For all stations other than Bankstown and Richmond January 1994 values were lower than the highest ever recorded.

Monthly variations in FFDI are shown in Fig. 1. Graphs of Parramatta data have been omitted because of similarities with Bankstown. Sydney data (Fig. 1b) have been presented previously by Gill and Moore (1994). Average FFDI values (lowermost graph in each chart) showed little variation throughout the year for all stations. Higher values were apparent for Richmond. Average maxima (middle graph in each chart) showed marked seasonality. At Wollongong on the coast, peak values occurred in September and December. Data for Bankstown and Liverpool (middle charts) showed a seasonal peak in December. The relatively high values for Richmond showed a broad 'peak' from October to January. Katoomba, at higher elevation and further inland than all other stations, showed a relatively sharp December–January peak. Record values for each month (uppermost graph in each chart) showed peaks between October and March.

Because of the fragmented nature of the data (Table 2), FFDI values were not available for all stations at equivalent times. Twenty two time periods were necessary to enable comparisons of FFDI to be made across stations at any common time. The only year in which all available stations (where two or more stations had data) recorded 'extreme' FFDI's was 1971. Of particular significance was the the first of October 1971 when all stations with available data showed 'extreme' FFDI values. Stations with no data at this time were Katoomba and Richmond. The only station without an 'extreme' value in January 1994 was Wollongong.

'Extreme' FFDI values were scattered in time and space but also often clustered in time at any one station. Thus two or more 'extremes' were often clustered to the extent that they occurred in the same month or week or on successive days. Bankstown had 4 successive days with FFDI in the 'extreme' range in January 1994 while Richmond had 5 'extremes' in 6 days in the same month. In November 1982, Richmond had 4 days — 2 consecutive — where 'extreme' FFDI values occurred. Bankstown had 3 consecutive 'extremes' in December 1972. Richmond and Bankstown had the highest average number of 'extreme' FFDI values per year despite having the shortest periods of data availability (Table 2). These results did not seem to be affected by the actual periods for which data were available.

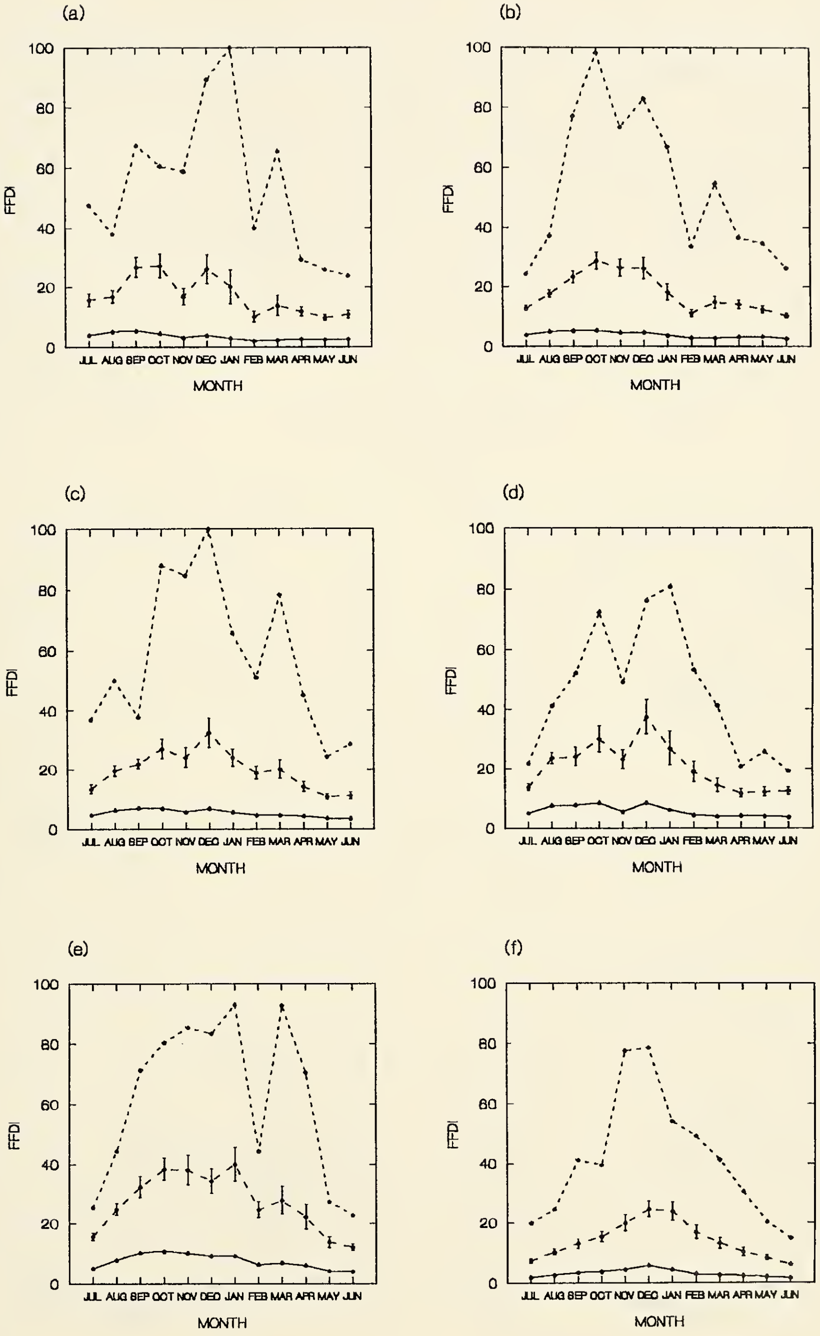

Fig. 1. Seasonal variations in Forest Fire Danger Index (FFDI). The lowermost line in each chart is the average daily 3pm FFDI. The middle line is the average maximum value of FFDI per month. The uppermost line is the highest value recorded for each month over the period of data availability. (a) Wollongong; (b) Sydney; (c) Liverpool; (d) Bankstown; (e) Richmond; (f) Katoomba.

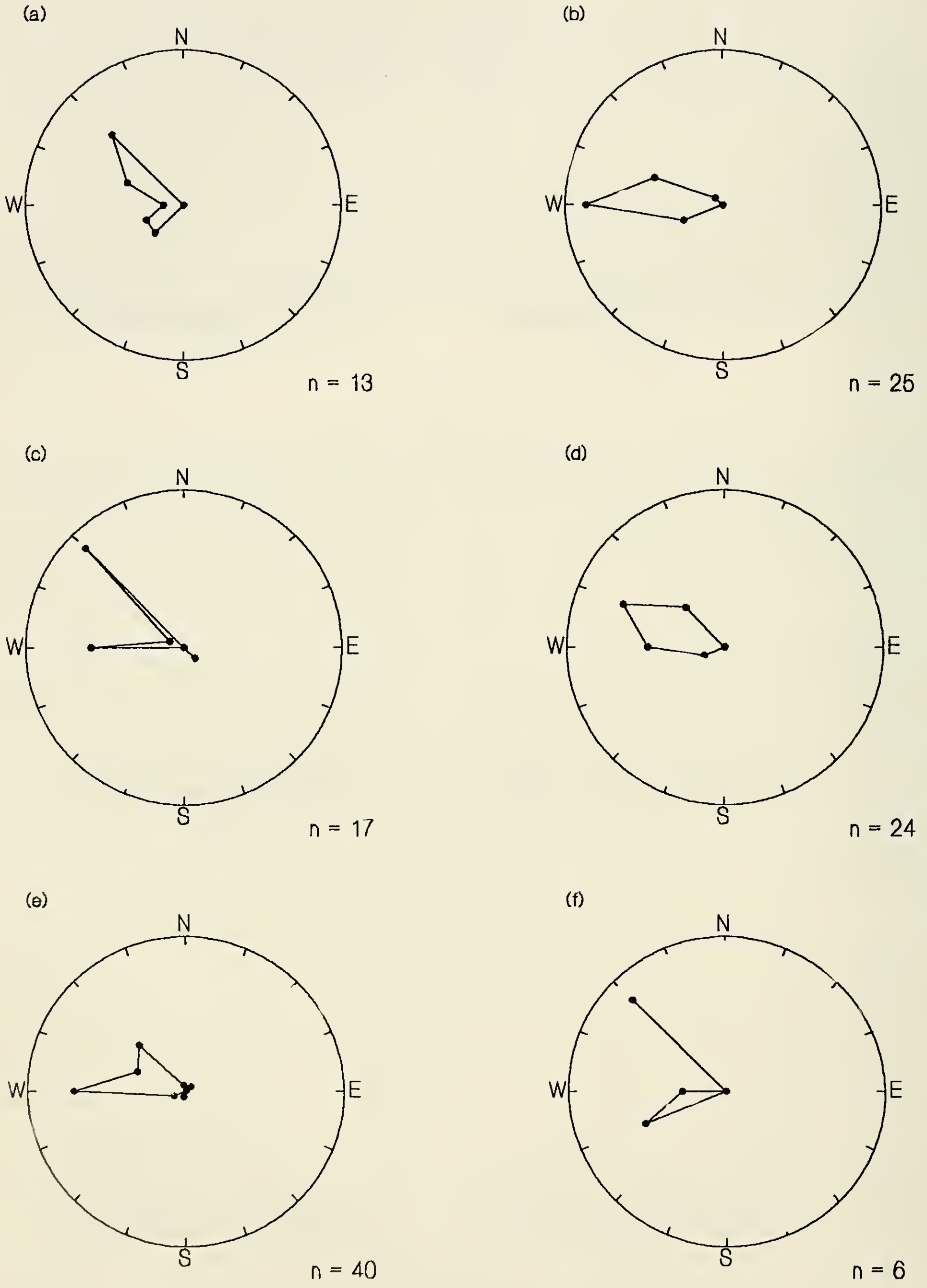

Fig. 2. Frequencies of wind directions when values of the Forest Fire Danger Index (FFDI) are 'extreme'.(a) Wollongong; (b) Sydney; (c) Liverpool; (d) Bankstown; (e) Richmond; (f) Katoomba.

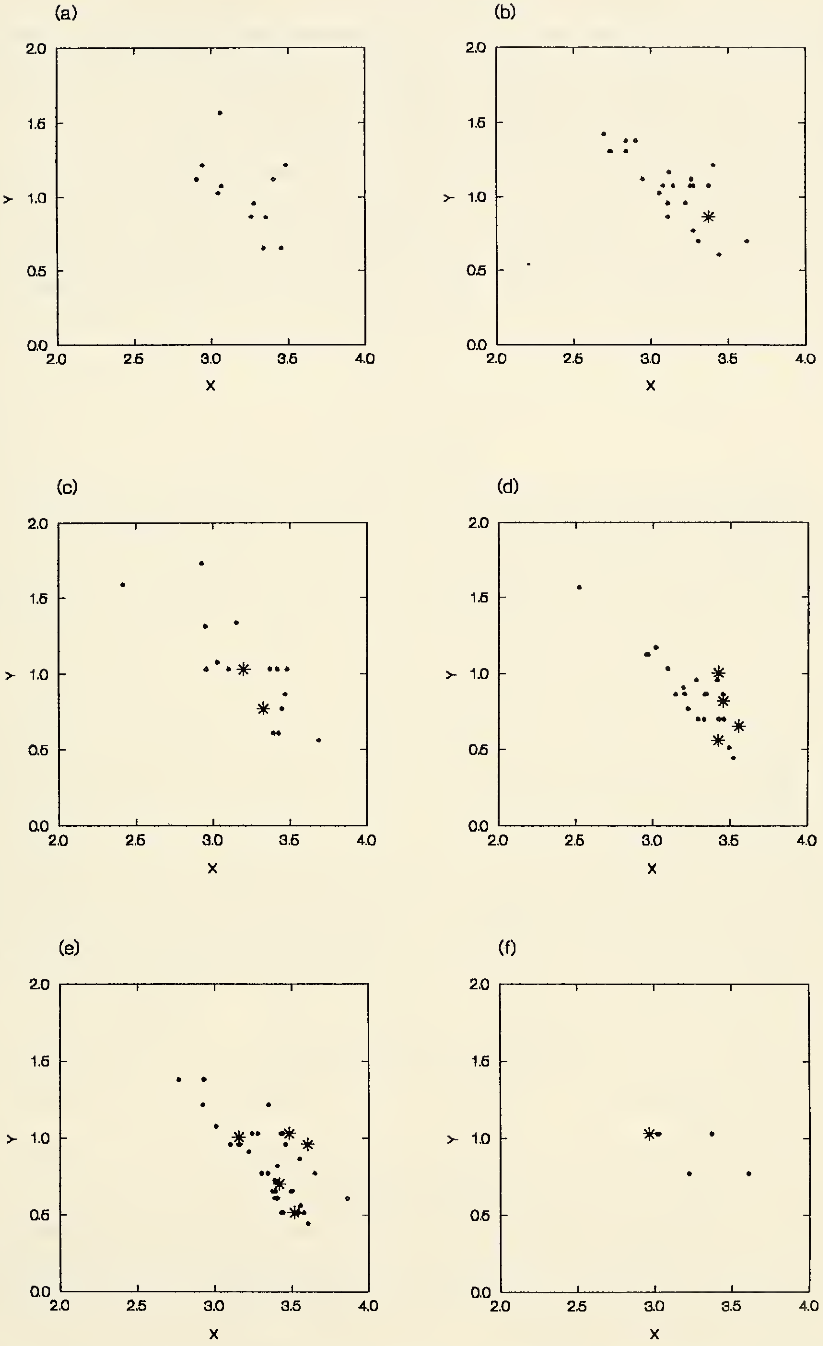

Fig. 3. 'Extreme' days plotted to reveal the contributions of wind (y-axis) or dryness (x-axis) to the value of Forest Fire Danger Index (FFDI). The further to the right the value is, the greater the dryness. The higher on the graph the value is the windier the condition. (a) Wollongong; (b) Sydney; (c) Liverpool; (d) Bankstown; (e) Richmond; (f) Katoomba. The asterisks refer to January 1994 data.

On 'extreme' days at 3pm, winds were predominantly from the westerly sector, especially the west and northwest (Fig.2). Separation of the wind and dryness contributions to FFDI (Fig.3) did not reveal any general trend in the January data to indicate unprecedented windiness or dryness in January 1994. However, the January 1994 'extreme' for Sydney was toward the dry end of the range (Fig.3b, also depicted in Gill and Moore 1994) while that for Katoomba was at the windy end (Fig. 3f).

For the 784 days between 1.12.91 and 22.1.94, wind speeds were all very highly correlated but the extent of variance explained was always less than 45% suggesting that accurate prediction of windspeed from one station to another is tenuous at best. Even the variance explained by regression of the windspeed at Sydney airport with that at Fort Denison (the new Sydney standard) was low. Correlation co-efficients between FFDI values at different stations were all statistically significant with up to 70% of the variance being explained.

DISCUSSION

Wind data are critical to fire-weather determination. The data may be misinterpreted or misleading if they are unrepresentative. They may be unrepresentative if they are inaccurate (more likely with Beaufait-scale determinations as at Katoomba, Liverpool and Parramatta) or the weather station is inappropriately located. The Bureau of Meteorology (personal communication) advised us of locational features of the pertinent meteorological stations. At Observatory Hill in Sydney itself, the anemometer was located on a 10m mast located on top of a three-storey building at a height of 22m above ground; now (1995) it is located at Fort Denison (on an island in Sydney Harbour) on a flagstaff yardarm. At Parramatta and Liverpool trees and buildings were observed to be close to meteorological screens in 1995 (A.M.Gill personal observations). Wollongong meteorological station was 'not located in accordance with Bureau standards'. Richmond and Bankstown weather stations, at local airports, appear to have been well placed, at least in recent years.

To ascertain the wind condition at a fire from a weather station, extrapolation or interpolation must take place. However, because of the difficulties in obtaining accurate and representative wind data from some of the weather stations used in our analyses, it is difficult to say what the wind conditions were at the various fire areas during January 1994 even if the ground there was flat. Given that the land in the fire areas often had a steep topography, local terrain effects on windspeed and direction seem likely. One wonders whether or not models 'anchored' to regional stations — selected by a process of systematic testing and cross regression against many sites — would allow more confident interpolations to be made in the future. Our correlation analyses showed non-predictive, but statistically significant relationships between windpeeds at various stations for a portion of the dataset.

FFDI was poorly predicted between stations but more variance was explained than that with wind. Record values at 3pm were recorded for a number of stations in January 1994 but these were not always the highest ever recorded when all months were considered. The most significant statistic for January 1994 may be the unprecedented (in time or at any station examined) 4 consecutive days with extreme FFDI values at Bankstown and the 5 days out of 6 with extreme FFDI values at Richmond. The length of the data set is relatively short for these stations but they are the stations with most 'very high' days as well as 'extremes' (Table 2).

Most of the data available was for 3pm, a time when FFDI may be expected to be at its highest for the day. This proposition has been tested with 3-hr data from Sydney by Gill and Moore (1994) and found to be reasonable — being much better than the use of either 6pm or 12 noon data.

Housing and other losses do not occur only at 3pm when FFDI reaches 'extreme' values. However, the maximum 3pm value for the day often provides a useful indicator for high values at other times of day. FFDI may have very low values in the mornings of days that reach 'extreme' values (e.g. Gill and Moore 1994 for Sydney).

Most fire–weather literature in the Sydney Region seems to be associated with the Blue Mountains. Colquhoun (1981) examined the synoptic situation and fire–weather indexes for Katoomba and Richmond for December 1977. The 16th December 1977 was one of the few 'extreme' days for Katoomba in our data set. Fifty houses were lost in the Blue Mountains on that day (Cunningham 1984). Other 'extreme' days in our Katoomba data set fall within, and only within, the 'bushfire seasons' determined by Cunningham (1984) from newspapers and travellers narratives, viz. 1977–78, 1979–80 and 1982–83. The 1994 events obviously occurred after Cunningham's study. Most losses of houses in the Blue Mountains have occurred in the November–December period (Cunningham 1984) when unprecedented values of 3pm FFDI have occurred (Fig. 1f). Fires that cause housing losses travelled mainly from the west and northwest, but also from the southwest (Cunningham 1984); these are the same directions from which the wind blows on 'extreme' days in the wider Sydney region (Fig.2).

Whether or not a series of fires similar to those of January 1994 can occur in the Sydney region again depends on the likelihood of a similar conjunction of weather conditions, fuels, ignition sources, locations of ignitions and suppression capabilities. As far as the weather is concerned, some aspects of the weather of January 1994 were unprecedented but, given the short period for which data were available (16 to 39 years), it seems likely that similar weather conditions will recur.

CONCLUSION

The January 1994 bushfires in Sydney were a major event. At a number of the regional weather stations, record 3pm fire–weather peaks were recorded for **January** of the weather data at hand. However, at some stations, peak values had been previously recorded at other times in other months. One Bankstown 3pm FFDI for January 1994 was an all-time record for 3pm but weather data were only available for a 16-year period. Successive days with 'extreme' FFDI values were an unprecedented feature of the data. The meteorological stations supplying data for these analyses were not necessarily well located to provide weather data pertinent to the fires.

ACKNOWLEDGEMENTS

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